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FINAL REPORT

U.S. NAVY MOBILITY FUELS: WORLDWIDE SURVEY AND ANALYSIS OF BOTH COMMERCIAL AND NAVY FUELS

by

Paul W. Woodward and Johanna Y. Shay

Prepared for

DAVID TAYLOR RESEARCH CENTER

CODE 2759, BETHESDA, MD 20084-5000

NIPER

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(U) Quality and worldwide availability of distillate fuels have become increasing concerns to the U. S. Department of Defense. In response to these concerns, the David Taylor Research Center (DTRC) has conducted a worldwide survey of such fuels through a contract with the National Institute for Petroleum and Energy Research (NIPER).

Representative fuels were collected at both Navy and commercial ports around the world through a NIPER subcontract to ABS Worldwide Technical Services (ABSTECH). The collected fuels were Naval Distillate Fuel (MIL-F-16884H, NATO F-76), Marine Gas Oil (MGO), Heavy Marine Gas Oil (HMGO), and Marine Diesel Fuel (MDF) for the Navy; Automotive/Truck Diesel for the Army; and Aviation Turbine Fuel (MIL-T-5624L, NATO JP-5) for the Naval Air Propulsion Center. The Navy F-76 fuel samples were characterized at NIPER by 44 different fuel property analyses. The Automotive/Truck samples were shipped to Southwest Research Institute in San Antonio, TX, and the JP-5 samples were shipped to the Naval Air Propulsion Center in Trenton, NJ, for characterization. (See reverse side)

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Twenty-five Navy Fuel Depots were surveyed by ABSTECH at the same time samples were collected to obtain logistical information regarding various fuel handling and storage capabilities. The objective of the depot surveys was to provide a data base from which to perform long range planning for Navy fuels purchase specifications.

This paper presents a project overview and summary of NIPER's role in the project. Peculiarities of fuel samples and problems encountered during testing are discussed.

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ABBREVIATIONS

ABSTECH	ABS Worldwide Technical Services, Paramus, NJ
ASTM	American Society for Testing & Materials
C/H	Carbon to hydrogen ratio
DTRC	David Taylor Research Center, Annapolis, MD
FSII	Fuel System Icing Inhibitor
H/C	Hydrogen to carbon ratio
Heat of Comb	Heat of combustion
HMGO	Heavy marine gas oil
MDF	Marine diesel fuel
mg KOH/g	Milligrams potassium hydroxide/gram
mg/L	Milligram/liter
MGO	Marine gas oil
MJ/kg	Megajoules/kilogram
mm^2/sec	Millimeters squared/second
NIPER	National Institute for Petroleum and Energy Research Bartlesville, OK

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ABSTRACT

Quality and worldwide availability of distillate fuels have become increasing concerns to the U.S. Department of Defense. In response to these concerns, the David Taylor Research Center (DTRC) has conducted a worldwide survey of such fuels through a contract with the National Institute for Petroleum and Energy Research (NIPER).

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Twenty-five Navy Fuel Depots were surveyed by ABSTECH at the same time samples were collected to obtain logistical information regarding various fuel handling and storage capabilities. The objective of the depot surveys was to provide a data base from which to perform long range planning for Navy fuels purchase specifications.

This paper presents a project overview and summary of NIPER's role in the project. Peculiarities of fuel samples and problems encountered during testing are discussed.

ADMINISTRATIVE INFORMATION

This work was sponsored by the Office of Naval Research (ONR 123) and funded through the David Taylor Research Center, Code 2759, via cooperative agreement DE-FC22-83FE60149 between the Illinois Institute of Technology Research Institute and the Department of Energy (DOE).

Contract administration functions were performed by the DOE Bartlesville Project Office. DTRC Code 2759 monitored and provided technical direction for the performance of this work.

BACKGROUND

The David Taylor Research Center (DTRC) is conducting the U.S. Navy Shipboard Mobility Fuels Research and Development Program, the purpose of which is to broaden the current fuel specification for Naval Distillate Fuel (MIL-F-16884H, NATO F-76) to include commercially-available, marine fuels. To more fully evaluate the available fuels and their possible acceptance for military use, it was necessary to obtain representative fuel samples worldwide for laboratory analysis.

In addition to evaluating properties of available fuels, the Navy needs information regarding facilities and fuel handling equipment in use at the various fuel depots around the world. This information, collected through surveys conducted at the depots, will be used in assessment of the potential impact of handling fuels of varying properties on depot operation and maintenance.

DISCUSSION

Sample collection and depot survey sites were selected by DTRC and Acurex Corporation personnel. Acurex Corporation, Mountain View, CA, provided project management services to DTRC. ABS Worldwide Technical Services, Inc. (ABSTECH) of Paramus, NJ, was contracted by NIPER to perform all sampling and depot surveys. This portion of the project is detailed in ABSTECH's final reports (Hanson and Stanford[1-7]).

Upon receipt at NIPER, 5-gallon samples in epoxy-lined cans were checked for container damages, logged into a notebook with a unique sample number together with the DTRC code, labeled, and stored at 40°F until testing commenced. Table 1 is a listing of samples received by code, type, origin, volume, and condition on arrival at NIPER. Most of the testing was conducted on sample groups of 10 or more.

Table 1. Survey sample inventory

Navy ID	NIPER ID	Fuel type	Country	Date received	Volume received, gallons	Volume on hand, gallons	Remarks (as received)
N-F-53	86NAVY0039	F-76	Bermuda	8-5-86	5	2	
N-F-61	86NAVY0072	F-76	Japan	10-21-86	5	2	
N-F-78	86NAVY00[illegible]	F-76	Spain	12-8-86	5	0.01	
N-F-81	86NAVY0082	F-76	Scotland	12-8-86	5	1	
N-F-77	86NAVY0088	F-76	Spain	12-19-86	5	2	can dented
N-F-59	87NAVY006S	F-76	Iceland	1-20-87	5	2	can dented
N-F-71	87NAVY007S	F-76	Panama	1-20-87	5	2	
N-F-83	87NAVY008S	F-76	England	1-20-87	5	2	
N-F-54	87NAVY012S	F-76	Crete	2-6-87	5	0.01	
N-F-73	87NAVY013S	F-76	Portugal	2-6-87	5	2	can dented
N-F-82	87NAVY036S	F-76	Scotland	3-18-87	5	2	can dented
N-F-57	87NAVY038S	F-76	Guam	3-18-87	5	2	
N-F-64	87NAVY039S	F-76	Japan	3-18-87	5	2	screw cap not tight
N-F-56	87NAVY040S	F-76	Diego Garcia	3-18-87	5	2	
N-F-63	87NAVY037S	F-76	Japan	3-18-87	5	2	*
N-F-72	87NAVY042S	F-76	Philippines	3-18-87	5	2	* screw cap off, fuel on top of can
N-F-55	87NAVY041S	F-76	Cuba	5-6-87	5	2	
N-F-74	87NAVY054S	F-76	Puerto Rico	5-6-87	5	2	*
N-F-66	87NAVY055S	F-76	Japan	5-6-87	5	2	*
N-F-84A	87NAVY066S	F-76	Puerto Rico	5-6-87	5	2	*
N-F-84B	87NAVY067S	F-76	Puerto Rico	5-6-87	5	5	*
N-F-85A	87NAVY068S	F-76	Scotland	5-6-87	5	2	*
N-F-85B	87NAVY069S	F-76	Scotland	5-6-87	5	5	* can dented, leaked
N-F-86A	87NAVY070S	F-76	Japan	5-6-87	5	2	* leaked
N-F-86B	87NAVY071S	F-76	Japan	5-6-87	5	5	* leaked
N-F-80	87NAVY072S	F-76	Scotland	5-6-87	5	0.01	* leaked
N-F-52	87NAVY073S	F-76	Azores	5-6-87	5	2	* leaked
N-F-79	87NAVY137S	F-76	Turkey	8-11-87	5	0.01	
C-M-19	86NAVY0067	MGO	France	10-20-86	5	2	
C-M-24	86NAVY0069	MGO	Kenya	10-20-86	5	0.01	
C-M-34	86NAVY0071	MGO	Thailand	10-20-86	5	1	
C-M-13	86NAVY0075	MGO	Belgium	11-14-86	5	2	
C-M-28	86NAVY0079	MGO	Saudi Arabia	12-8-86	5	1	screw cap not tight
C-M-21	86NAVY0080	MGO	Indonesia	12-8-86	5	2	
C-M-36	86NAVY0087	MGO	Venezuela	12-19-86	5	2	can dented
C-M-14	87NAVY003S	MGO	Brazil	1-12-87	5	2	
C-M-23	87NAVY011S	MGO	Japan	2-6-87	5	2	can dented
C-M-11	87NAVY030S	MGO	Australia	3-18-87	5	2	
C-M-12	87NAVY033S	MGO	Australia	3-18-87	5	0.01	
C-M-25	87NAVY034S	MGO	Netherlands	3-18-87	5	2	
C-M-33	87NAVY035S	MGO	Sweden	3-18-87	5	0.01	
C-M-30	87NAVY044S	MGO	Singapore	3-19-87	5	2	
C-M-29	87NAVY045S	MGO	Senegal	3-19-87	5	2	

* Refrigerated storage out of control, temperature climbed to approximately 120° F for about 36 hours prior to sample analysis.

Table 1. Survey sample inventory--continued

Navy ID	NIPER ID	Fuel type	Country	Date received	Volume received, gallons	Volume on hand, gallons	Remarks (as received)
C-M-3	87NAVY053S	MGO	England	5-6-87	5	0.01	*
C-M-18	87NAVY056S	MGO	Egypt	5-6-87	5	1	*
C-M-27	87NAVY057S	MGO	Philippines	5-6-87	5	0.01	*
C-M-20	87NAVY058S	MGO	Greece	5-6-87	5	2	*
C-M-17	87NAVY059S	MGO	England	5-6-87	5	2	*
C-M-37A	87NAVY060S	MGO	Singapore	5-6-87	5	1	*
C-M-37B	87NAVY061S	MGO	Singapore	5-6-87	5	5	*
C-M-40A	87NAVY062S	MGO	Philippines	5-6-87	5	2	*
C-M-40B	87NAVY063S	MGO	Philippines	5-6-87	5	5	*
C-M-39A	87NAVY064S	MGO	Greece	5-6-87	5	2	*
C-M-39B	87NAVY065S	MGO	Greece	5-6-87	5	5	*
C-M-88	87NAVY132S	MGO	Malaysia	8-11-87	5	2	
C-M-48	87NAVY135S	MGO	Italy	8-11-87	5	2	
C-M-87	87NAVY136S	MGO	Korea	8-11-87	5	2	
C-M-43	87NAVY137S	MGO	Peru	8-19-87	5	0.01	
C-M-26	87NAVY144S	MGO	Pakistan	8-26-87	5	2	
C-M-42	87NAVY147S	MGO	India	8-27-87	5	2	
C-M-45	87NAVY148S	MGO	U. Arab Emirates	8-27-87	5	1	
C-M-49	87NAVY149S	MGO	Malta	8-27-87	5	2	
C-M-89	87NAVY158S	MGO	Canada	9-22-87	5	2	
C-M-44	87NAVY184S	MGO	Sri Lanka	10-29-87	5	2	
C-M-47	87NAVY185S	MGO	Chile	10-29-87	5	2	
C-H-21	86NAVY0081	HMGO	Indonesia	12-8-86	5	0.01	
C-H-30	86NAVY0084	HMGO	Singapore	12-19-86	5	2	can dented
C-H-36	86NAVY0086	HMGO	Venezuela	12-19-86	5	2	can dented
C-H-23	87NAVY010S	HMGO	Japan	2-6-87	5	2	can dented
C-H-87	87NAVY133S	HMGO	Korea	8-11-87	5	2	
C-H-43	87NAVY137S	HMGO	Peru	8-19-87	5	2	
C-D-24	86NAVY0068	MDF	Kenya	10-20-86	5	2	
C-D-34	86NAVY0070	MDF	Thailand	10-20-86	5	2	
C-D-23	86NAVY0076	MDF	Japan	11-14-86	5	2	
C-D-30	86NAVY0077	MDF	Singapore	11-14-86	5	2	
C-D-36	86NAVY0085	MDF	Venezuela	12-19-86	5	2	can dented
C-D-33	87NAVY031S	MDF	Sweden	3-18-87	5	2	can dented
C-D-12	87NAVY032S	MDF	Australia	3-18-87	5	2	
C-D-15	87NAVY103S	MDF	Colombia	6-10-87	5	2	*
C-D-26	87NAVY145S	MDF	Pakistan	8-26-87	5	2	
C-D-42	87NAVY146S	MDF	India	8-27-87	5	2	

* Refrigerated storage out of control, temperature climbed to approximately 120° F for about 36 hours prior to sample analysis.

All laboratory data were initialed in the lab books by the analyst performing each test, and the initials were reported on the final sample analysis data sheets. Initials of the analysts working on this project are decoded in the Appendix.

Prior to analysis, samples in the original cans were shaken on a mechanical shaker and separated into aliquots for distribution to the various test centers within the laboratory. One sample from each group of 10 was used as an internal quality control sample. It was split into two fractions; one was given a different lab number and analyzed together with the other samples as a blind or quality control sample. One gallon of each sample was poured into an epoxy-lined metal can, blanketed with nitrogen, and shipped to the Naval Research Laboratory in Washington, DC. Any sample remaining in the original can was blanketed with nitrogen and stored at 40°F.

Problems were encountered with the temperature control circuitry of the 40° F refrigerated storage facility. This malfunction occurred during hot weather and during a weekend period, 6-7 June 1987. Temperature inside the storage area reached 120° F and remained there for about 36 hours. Samples exposed to this extreme temperature prior to being analyzed are marked with an asterisk in Table 1. Other high temperature (<100° F) excursions of shorter duration occurred 11, 14, 16 June 1987 and 23-24 August 1987.

Prior to the malfunction, temperature inside the facility was monitored with a chart recorder which was checked on an intermittent basis, two or three times weekly. Afterwards, a temperature alarm system was purchased and installed which constantly monitored the temperature inside the storage area and if the temperature excursions exceeded ±10° F, an alarm was set off in the plant operator's office for remedial action. Normal excursions were about ±2° F dur ng a 24-hour period.

SAMPLE ANALYSES

Table 2 shows the characterization protocol that was followed for each sample, including quality control samples. Standard methods of the American Society for Testing and Materials (ASTM) (Annual Book for ASTM Standards[8]) were used as much as possible. A collection of applicable test methods is published in a Navy report (DTNSRDC-PASD-CR-6-87[9]). In addition to the ASTM methods in the Navy report, appropriate military and industrial methods, and modifications of these, are included.

Difficulties were encountered with some samples when attempting to test according to standard procedures, resulting in necessary procedure modifications. Very few problems were encountered with the F-76 fuels; most were from analysis of the commercial marine gas oils (MGO), heavy marine gas oils (HMGO), and marine diesel fuels (MDF). The following is a discussion of the problems and method modifications.

Distillation

A few samples showed signs of cracking during distillation according to ASTM method D 86. Sample C-M-27 from the Phillippines showed evidence of severe cracking as shown in Figures 1-4. There was a large amount of smoke and excess condensation of a yellow-brown waxy material in the distillation flask, condenser and receiver. This sample was subsequently distilled under vacuum according to ASTM D 1160 procedures. Cracking was again observed at about 70% overhead. Other samples requiring vacuum distillation were C-M-40, C-D-34, and C-H-43.

Table 2. Characterization Protocol

Fuel Property	Units	Test Method
Distillation		
Initial Boiling Point	°C	D 86
5% Point	°C	D 86
10% Point	°C	D 86
20% Point	°C	D 86
30% Point	°C	D 86
40% Point	°C	D 86
50% Point	°C	D 86
60% Point	°C	D 86
70% Point	°C	D 86
80% Point	°C	D 86
90% Point	°C	D 86
95% Point	°C	D 86
End Point	°C	D 86
Residue	vol. %	D 86
Loss	vol. %	D 86
Initial Boiling Point	°C	D 2887
5% Point	°C	D 2887
10% Point	°C	D 2887
20% Point	°C	D 2887
30% Point	°C	D 2887
40% Point	°C	D 2887
50% Point	°C	D 2887
60% Point	°C	D 2887
70% Point	°C	D 2887
80% Point	°C	D 2887
90% Point	°C	D 2887
95% Point	°C	D 2887
End Point	°C	D 2887
Physical		
Specific Gravity, @ 15.6° C		D 1298
Specific Gravity, @ 15.6° C		D 4052
Gravity	°API	calculate
Viscosity @ 40° C	mm^2/sec	D 445
Viscosity @ 100° C	mm^2/sec	D 445
Flash Point	°C	D 93
Cloud Point	°C	D 2500
Pour Point	°C	D 97
Demulsification @ 25° C	minutes	D 1401
Color		D 1500
Appearance		D 4176
Surface Tension	dynes/cm	D 1331
Interfacial Tension	dynes/cm	D 1331
Water & Sediment	vol. %	D 2709
Particulates	mg/L	D 2276
Asphaltenes	wt. %	D 2007
Polars	wt. %	D 2007
Chemical		
Sulfur	wt. %	D 4294
Acid Number	mg KOH/g	D 974
Acid Number	mg KOH/g	D 664
Corrosion @ 100° C		D 130
Carbon Residue, on 10% bottoms	wt. %	D 524
Accelerated Stability	mg/100 mL	D 2274
FSII	wt. %	FSTM 791/5327
Neutrality	Acid/Neutral	FSTM 791/5101
Combustion		
Net Heat of Combustion	MJ/kg	D 2382
Hydrogen Content	wt. %	PE 240
Carbon Content	wt. %	PE 240
H/C; C/H Ratio		calculate
Cetane No.		D 613
Cetane Index		D 976
Diesel Index		calculate
Aniline Point	°C	D 611
Aromatics	wt. %	D 2007
Saturates	wt. %	D 2007
Ash	wt. %	D 482
Trace Metals		
Aluminum	ppm wt.	D 3605 *
Calcium	ppm wt.	D 3605 *
Copper	ppm wt.	D 3605 *
Iron	ppm wt.	D 3605 *
Lead	ppm wt.	D 3605 *
Nickel	ppm wt.	D 3605 *
Silicon	ppm wt.	D 3605 *
Potassium	ppm wt.	D 3605 *
Sodium	ppm wt.	D 3605 *
Vanadium	ppm wt.	D 3605 *

* Modified method

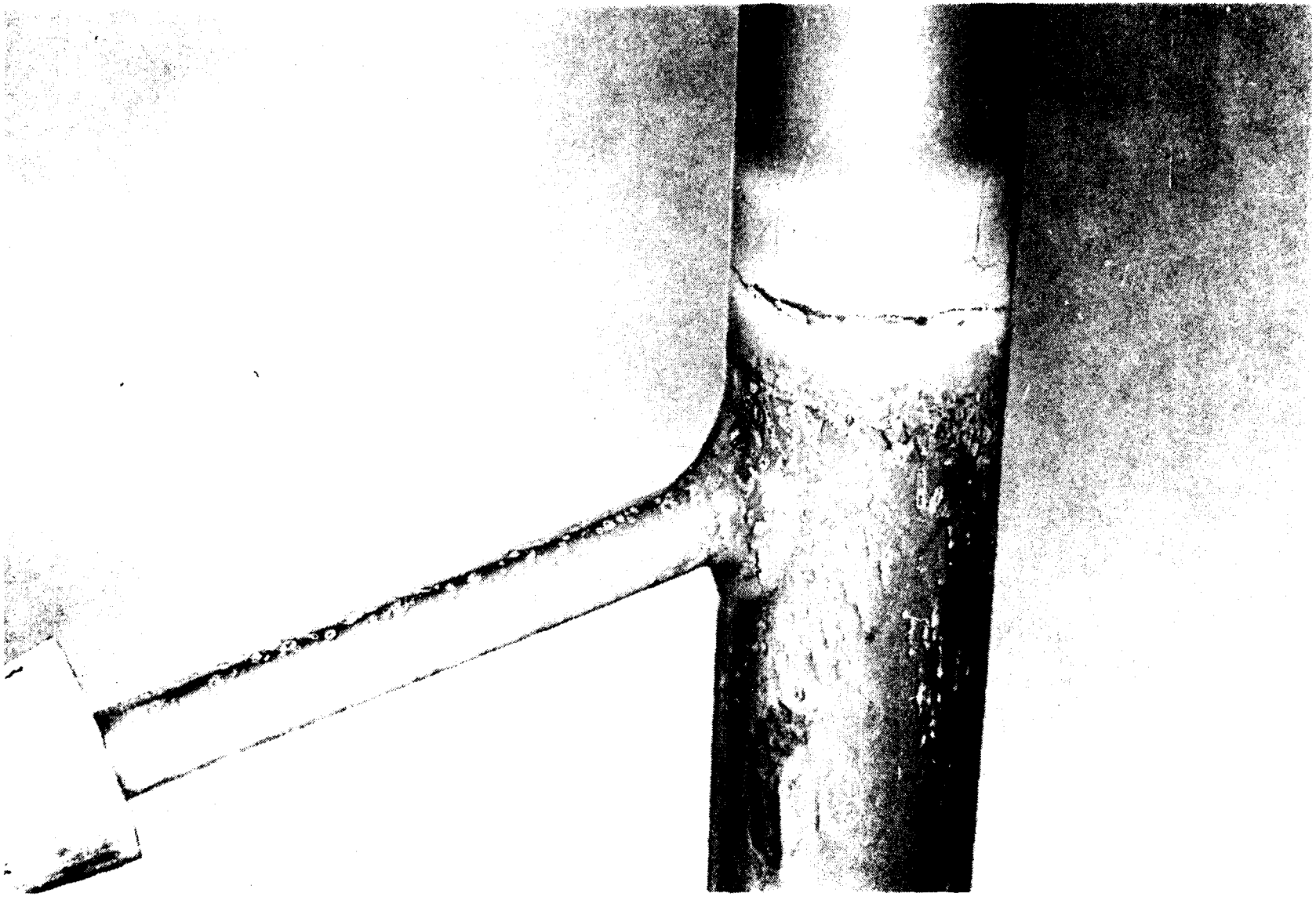

Fig. 1 Distillation of sample C-M-27, flask at point of overhead take-off at the time distillation was stopped

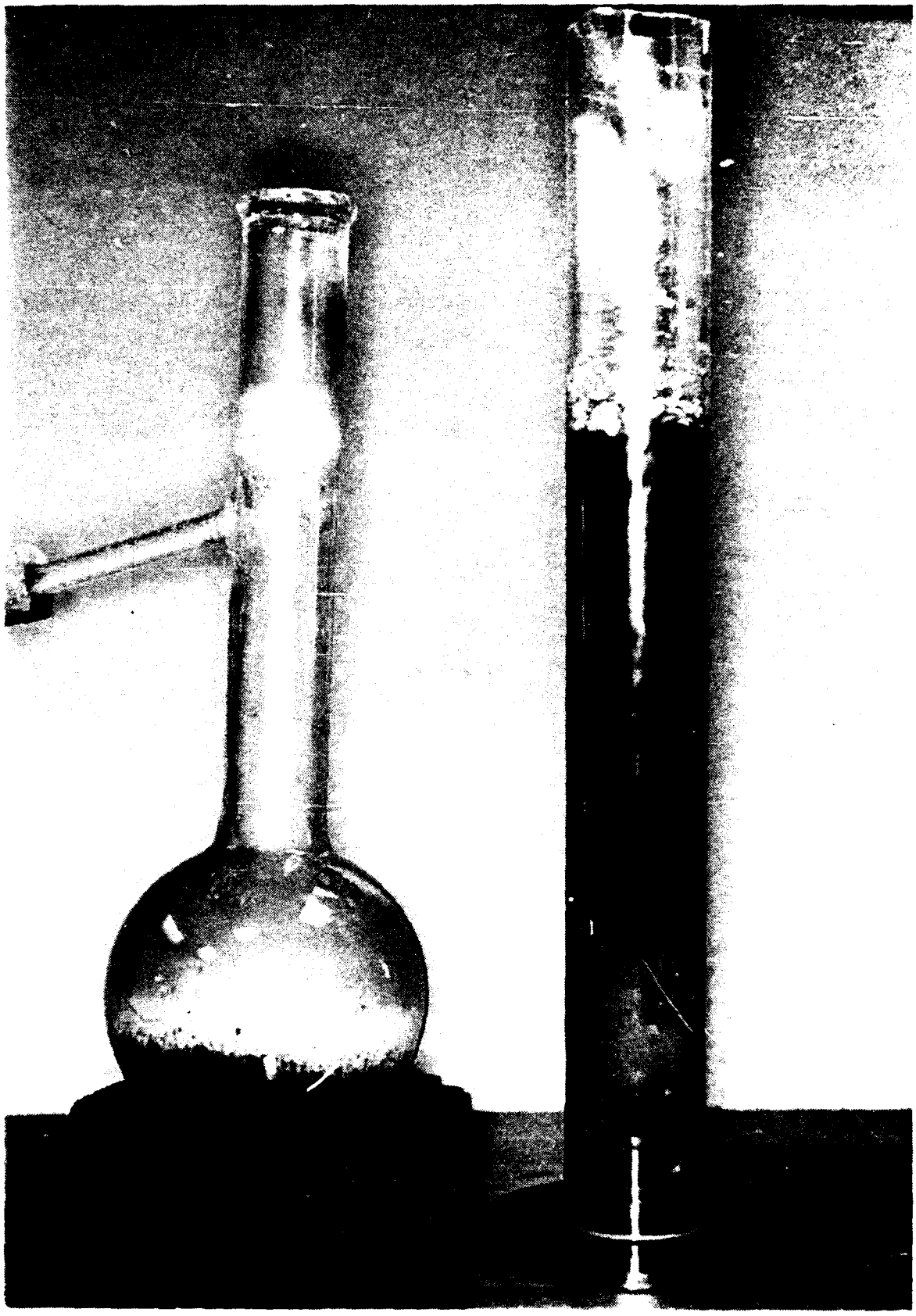

Fig. 2. Distillation of sample C-M-27, flask and receiver showing abnormal condensation of materials in both

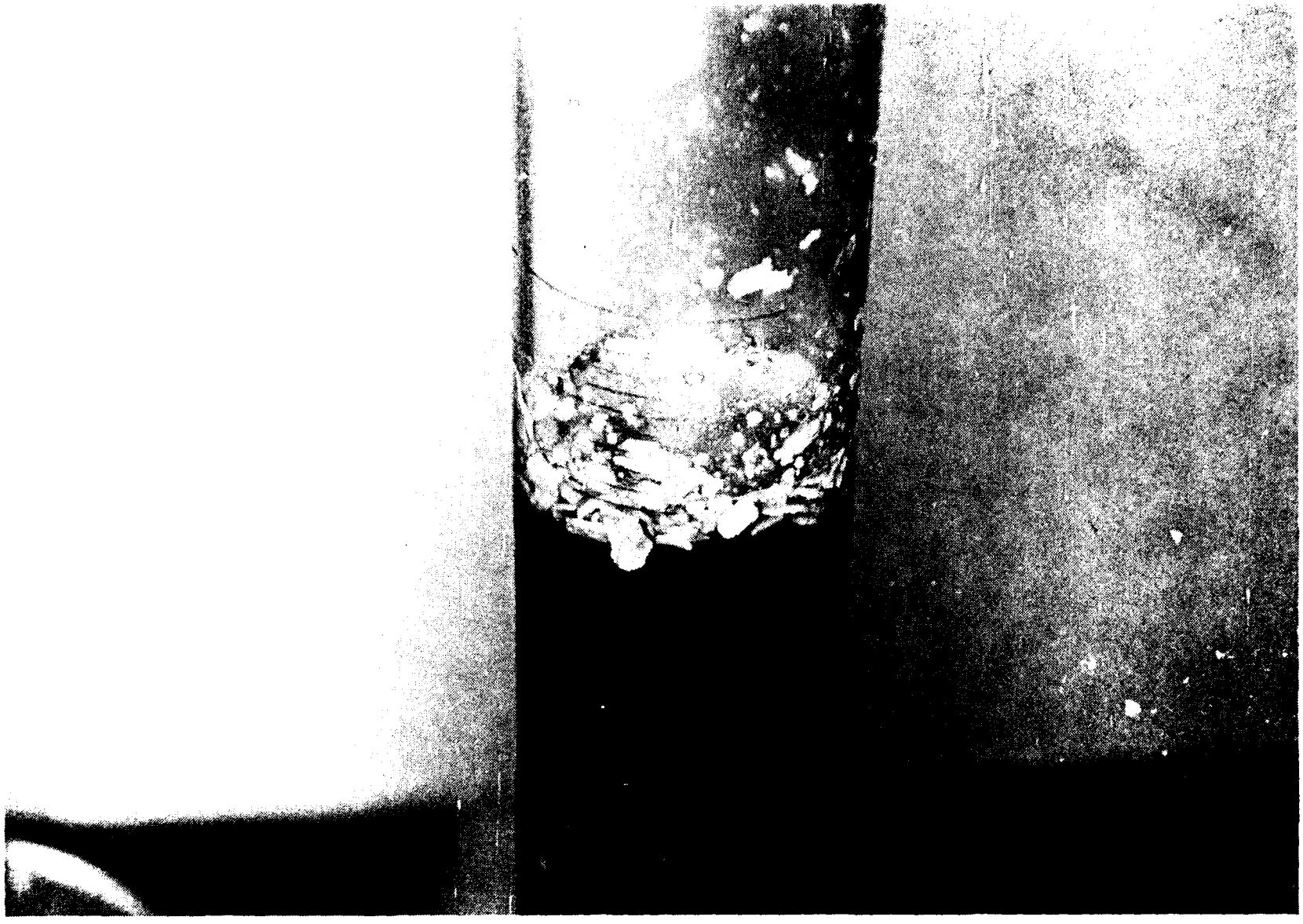

Fig. 3. Distillation of sample C-M-27, upper portion of receiver

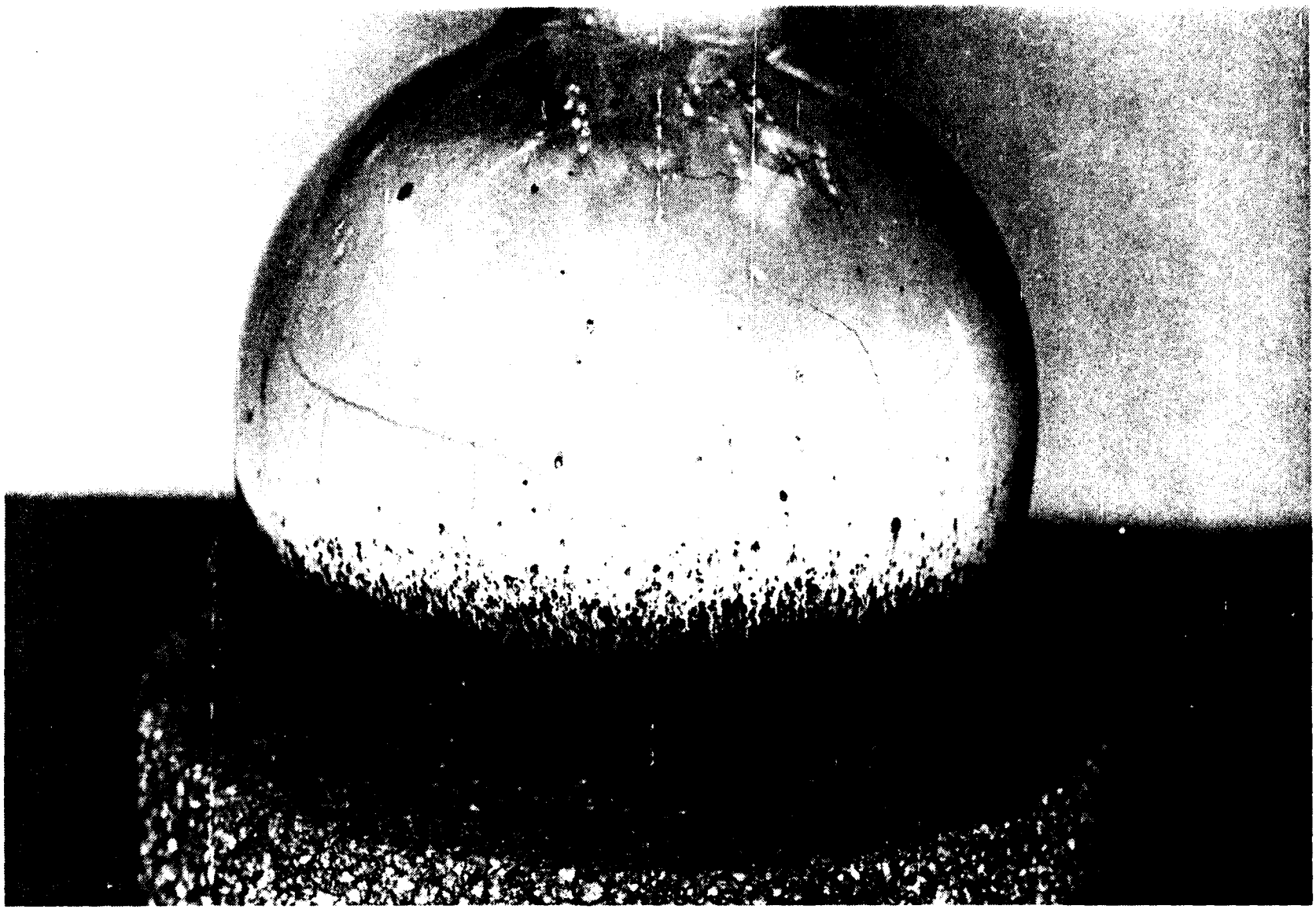

Fig. 4. Distillation of sample C-M-27, still pot showing a coating of yellow-brown waxy material

Simulated distillation (sim-dis) by gas chromatography (ASTM D 2887) is designed for samples with an end point of less than 565°C, and was therefore not appropriate for some of the heavier or higher boiling samples. There is another GC simulated distillation procedure (ASTM proposed crude method P 167) that may be used for these type samples. It was used in this study for samples C-D-24, C-D-30, and C-D-34. It is common for the sim-dis initial boiling point to be lower and the end point higher than from actual distillation. The 50% distilled data are, however, typically in good agreement.

Particulates

The ASTM test method for particulates, D 2276 "Particulate Contaminant in Aviation Turbine Fuels," specifies that a 3.785 to 5 liter sample be filtered through a 0.8 micron pore-size filter. Filterable sample volumes for the samples in this study ranged from a few milliliters to about 4 liters. Most were on the low side because of rapid filter plugging. Some samples were heated in the filter funnel in an attempt to increase filterability with minimal success. Pentane (250 ml, HPLC grade) was used as the flushing fluid instead of petroleum ether as suggested in ASTM method D 2276, because of its higher purity and safety factor. Filters were dried at 100°C for 30 minutes and then cooled for 30 minutes to room temperature before weighing.

Pore size is not the only consideration for filterability. Precipitation of gums or waxes and other organic compound interactions can also have an adverse effect on filterability. ASTM method D 2276 as written is not appropriate for many marine fuels. The scope of ASTM method states that it is for determination of contaminants in aviation turbine fuels. Most of the marine fuels were heavier and

contained more filter-plugging components than aviation turbine fuels: waxes, gums, asphaltenes and particulates. This test method was performed because it is a MIL-F-16884H specification requirement.

Carbon Residue

Troubles were experienced in determination of the Ramsbottom carbon residue on 10% distillation bottoms for certain samples. The 10% bottoms are what remains in the distillation pot after distilling 90% of the charge. Samples with carbon residue values above about 0.2 wt % were the most troublesome for unknown reasons. Some possible explanations could be: non-homogeneous sampling, insufficient burn for heavy components, loss of carbonizable sample through flashing during the initial burn, etc. Fortunately, most of the samples yielded reproducible results. Because of their heavy nature, carbon residue values were determined on neat (whole, non-distilled) samples for fuels C-M-27, C-M-40, C-M-42, C-H-43, and C-D-34.

Oxidation Stability

The ASTM test for accelerated oxidation stability, D 2274, also proved troublesome. Some of the heavier samples could not be filtered as prescribed in the standard method. Modifications aimed at improvement included heating both the samples and filter funnel and using 7-cm diameter filters instead of the specified 2.4-cm filters. These measures helped with some fuels, but others were still not amenable to testing. Color (ASTM D 1500) was determined before and after stability testing.

Elemental Analysis

An ASTM standard is not yet available for elemental (carbon/hydrogen) analysis. However, the method used at NIPER with a Perkin-Elmer 240C analyzer is generally acceptable within the petroleum industry. Additionally, there is an active ASTM Study Group working to develop an appropriate standard method using this type of an analysis. Acetanilide and kerosene are used as calibration and quality control samples. Precision values at NIPER were established from 55 analyses of acetanilide over a period of 9 months. The standard deviation for these samples of acetanilide was 0.18 wt % for carbon and 0.11 wt % for hydrogen. The instrument manufacturer states a precision value of 0.3 wt % absolute for this method.

Cetane Number

Cetane numbers were determined at Phillips 66 R&D Center in Bartlesville, OK, using a cetane engine as specified in ASTM D 613. A reference fuel was analyzed with each sample. Erratic meter readings were observed on the cetane engine for some fuels because of peculiar fuel characteristics. Most of the problems with the cetane test occurred with very dark and viscous fuels (C-M-26, C-M-45, C-D-26, C-D-34, C-D-42, C-H-21, and C-H-43). Part of the difficulty in obtaining a steady reading was the inability of the fuels to produce an acceptable spray pattern off the fuel injector nozzle.

Metals

Metals were determined with a modified ASTM D 3605 atomic absorption (AA) procedure. The low concentration of metals in most fuels necessitated ashing portions of the samples prior to AA analyses. Details of the procedure are given in reference 9. Ashing of samples and analysis by flameless AA resulted in an improvement in sensitivity and lower detection limit by a factor of about 100.

Fuel Property Ranges

Tables 3-6 list low, median, and high values of selected fuel properties by fuel type and ID code. If the median fell between two samples, the value listed is the average of the two.

Twenty-five Navy F-76 fuels listed in Table 3 from various ports in 16 countries were analyzed as part of this survey. These were the cleanest fuels with the highest API gravity, and they gave the least analysis problems using standard analysis methods. The gravity values for the 25 fuels ranged from 34.4 to 39.0 °API, and the boiling range spread for the 50 vol % distilled point was only 26.5°C. Sixteen of the 25 had a water and sediment value of <0.005 wt %. The spread of values for carbon residue on 10% bottoms was also low at 0.10 - 0.15 wt %. Accelerated stability had a wider distribution of values: 0.14 - 2.93 mg/100mL. Combustion properties held within a fairly narrow range except for aromatics and saturates for fuels N-F-53 (Bermuda) and N-F-61 (Japan). Fuel N-F-74 from Puerto Rico had high copper, iron, and lead values compared to the other F-76 fuels.

Thirty-four commercial MGOs listed in Table 4 were collected from 29 countries and analyzed in NIPER's laboratories. Fuels C-M-27 and C-M-40, both from the Philippines, seem to be the poorest quality fuels in this set. They have low cetane number; low heat of combustion; and high aromatics, polars, asphaltenes, and metals contents. During vacuum distillation of these two at 1 mm Hg, cracking occurred after about 80% distilled.

Sulfur values for the MGO fuels ranged from 0.03 wt % for one of the better fuels, C-M-21 from Indonesia, to 1.13 wt % for C-M-26 from Pakistan. Flash points ranged from 58 to 100°C.

Table 3. Analytical data for Naval Distillate Fuels, F-76 (25 samples)

Fuel Property	Low		Median			High	
	ID	Value	ID	ID2	Value	ID	Value
Distillation, D 86							
Initial Boiling Point, °C	N-F-77	182.0	N-F-74	——	190.5	N-F-53	212.2
50% Point, °C	N-F-59	262.0	N-F-57	——	282.0	N-F-56	288.5
90% Point, °C	N-F-59	315.5	N-F-63,81	——	335.5	N-F-77	349.0
End Point, °C	N-F-59	346.5	N-F-63	——	363.0	N-F-77	379.0
Distillation, D 2887							
Initial Boiling Point, °C	N-F-79	117.5	N-F-72	——	132.5	N-F-83	142.0
50% Point, °C	N-F-59	268.5	N-F-57	——	286.0	N-F-81	296.5
90% Point, °C	N-F-59	340.5	N-F-80,85	——	361.0	N-F-72,77	373.5
End Point, °C	N-F-53	402.0	N-F-63	——	423.5	N-F-77	446.5
Specific Gravity @ 15.6° C	N-F-59	0.8298	N-F-56	——	0.8437	N-F-82	0.8530
Gravity, °API	N-F-82	34.4	N-F-77	——	36.2	N-F-59	39.0
Viscosity @ 40° C, mm²/sec	N-F-59	2.441	N-F-54	——	3.122	N-F-72	3.552
Viscosity @ 100° C, mm²/sec	N-F-86	0.850	N-F-54	——	1.230	N-F-72	1.341
Flash Point, °C	N-F-77	65.5	(3 fuels)	——	75.5	N-F-82	81.5
Cloud Point, °C	N-F-59	-15	(6 fuels)	——	-5	N-F-77,79	0
Pour Point, °C	N-F-59	-27	(8 fuels)	——	-9	(4 fuels)	-6
Surface Tension, dynes/cm	N-F-79	26.5	N-F-73	——	28.2	N-F-53	31.6
Interfacial Tension, dynes/cm	N-F-56	10.5	N-F-63	——	15.5	N-F-82	21.0
Water & Sediment, vol. %	(16 fuels)	<0.005	(16 fuels)	——	<0.005	N-F-79	0.015
Particulates, mg/L	N-F-82	0.05	N-F-72	——	1.41	N-F-84	6.20
Sulfur, wt. %	N-F-59	0.24	N-F-54	N-F-74	0.60	N-F-61	0.96
Acid No., mg KOH/g	N-F-53	<0.01	(4 fuels)	——	0.05	N-F-63	0.08
Carbon Residue,							
on 10% bottoms, wt. %	N-F-55,86	0.10	(6 fuels)	——	0.12	N-F-74,79	0.15
Accelerated Stability, mg/100 mL	N-F-82	0.14	N-F-56	——	0.89	N-F-74	2.93
Heat of Combustion, MJ/kg	N-F-53	42.353	N-F-72	——	42.678	N-F-59	42.966
Hydrogen Content, wt. %	N-F-61	13.05	N-F-55	——	13.32	N-F-59	13.69
Carbon Content, wt. %	N-F-61	85.58	N-F-80	——	86.10	N-F-59	86.84
Cetane No.	N-F-78	48.6	N-F-56	——	51.8	N-F-72	56.3
Cetane Index	N-F-74	49.7	N-F-73	——	52.1	N-F-86	54.2
Diesel Index	N-F-82	53.1	N-F-85	——	56.8	N-F-59	61.7
Aniline Point, °C	N-F-77	66.20	N-F-78	——	69.25	N-F-74	77.00
Aromatics, wt. %	N-F-53	29.0	N-F-66	N-F-82	39.1	N-F-61	53.8
Polars, wt. %	N-F-53,66	0.1	N-F-73	N-F-63	0.4	N-F-71	0.7
Saturates, wt. %	N-F-61	45.8	N-F-82	N-F-66	60.7	N-F-53	69.0
Asphaltenes, wt. %		<0.1			<0.1		<0.1
Ash, wt. %	(13 fuels)	<0.0001	(13 fuels)	——	<0.0001	N-F-52	0.0019
Aluminum, ppm wt.	(12 fuels)	<0.02	N-F-63	——	0.02	N-F-80	0.07
Calcium, ppm wt.	N-F-53	<0.02	N-F-64	——	0.14	N-F-71	0.28
Copper, ppm wt.	(5 fuels)	0.02	N-F-82	——	0.06	N-F-74	0.43
Iron, ppm wt.	N-F-77	<0.02	N-F-85	——	0.05	N-F-74	0.33
Lead, ppm wt.	N-F-57, 59,73	0.01	N-F-54	——	0.03	N-F-74	0.55
Nickel, ppm wt.	(13 fuels)	<0.01	(13 fuels)	——	<0.01	N-F-72	0.09
Silicon, ppm wt.	(10 fuels)	<0.01	(8 fuels)	——	<0.04	N-F-79	0.34
Potassium, ppm wt.	(14 fuels)	<0.01	(14 fuels)	——	<0.01	N-F-78	0.09
Sodium, ppm wt.	(4 fuels)	<0.04	N-F-73	——	0.14	N-F-61	0.30
Vanadium, ppm wt.	N-F-53	<0.02	(16 fuels)	——	<0.03	N-F-63	0.06

Table 4. Analytical data for Marine Gas Oils (MGO, 34 samples)

Fuel Property	Low		Median			High	
	ID	Value	ID	ID2	Value	ID	Value
Distillation, D 86/1160							
Initial Boiling Point, °C	C-M-43	165.5	C-M-25	C-M-34	192.0	C-M-19	229.0
50% Point, °C	C-M-33	226.5	C-M-42	C-M-11	285.8	C-M-27	339.0
90% Point, °C	C-M-33	295.0	C-M-29	C-M-23	344.8	C-M-45	376.0
End Point, °C	C-M-33	320.5	C-M-25	C-M-49	377.0	C-M-45	395.5
Distillation, D 2887							
Initial Boiling Point, °C	C-M-29	100.0	C-M-12	C-M-23	125.0	C-M-19	156.0
50% Point, °C	C-M-33	229.5	C-M-39	C-M-29	286.8	C-M-21	319.0
90% Point, °C	C-M-33	317.0	C-M-28,89	——	370.0	C-M-14,45	398.5
End Point, °C	C-M-33	365.5	C-M-39	C-M-25	440.5	C-M-14	490.0
Specific Gravity, @ 15.6° C	C-M-33	0.8198	C-M-26	C-M-44	0.8460	C-M-27	0.9155
Gravity, °API	C-M-40	23.1	C-M-44	C-M-26	35.8	C-M-33	41.3
Viscosity @ 40° C, mm²/sec	C-M-33	1.741	C-M-24	C-M-18	3.333	C-M-27	11.97
Viscosity @ 100° C, mm²/sec	C-M-33	0.8314	C-M-18	C-M-29	1.322	C-M-40	3.006
Flash Point, °C	C-M-33	58.5	C-M-34	C-M-44	76.0	C-M-19	100.5
Cloud Point, °C	C-M-33	-22	C-M-28	——	0	C-M-21, 34,42,45	11
Pour Point, °C	C-M-33	-48	(6 fuels)	——	-6	C-M-27,40	12
Demulsification @ 25° C, min.	C-M-13, 26,33	1	(13 fuels)	——	2	C-M-89	5
Color	C-M-19, 33,87	L0.5	C-M-44	C-M-20	L2.25	C-M-27,40	D8.0
Surface Tension, dynes/cm	C-M-23	24.7	(3 fuels)	——	27.6	C-M-27	29.9
Interfacial Tension, dynes/cm	C-M-28	7.5	C-M-20	C-M-34	17.0	C-M-26	24.0
Water & Sediment, vol. %	(21 fuels)	<0.005	(21 fuels)	——	<0.005	C-M-40	0.480
Particulates, mg/L	C-M-24	0.65	C-M-21	——	2.08	C-M-39	12.41
Filtered, vol/mL	C-M-40	20	C-M-43	C-M-11	2000	C-M-20	3900
Sulfur, wt. %	C-M-21	0.03	C-M-47	C-M-88	0.53	C-M-26	1.13
Acid No., mg KOH/g	C-M-26,28	0.02	(6 fuels)	——	0.04	C-M-36	0.98
Carbon Residue, on 10% bottoms, wt. %	C-M-33	0.06	(10 fuels)	——	0.12	C-M-89	0.24
Accelerated Stability, mg/100 mL	C-M-26	0.10	C-M-30	C-M-37	0.37	C-M-89	3.93
FSII, wt. %	C-M-19, 24,34	<0.001	(4 fuels)	——	0.046	C-M-43, 48,89	0.066
Heat of Combustion, MJ/kg	C-M-27	41.430	C-M-34	C-M-39	42.636	C-M-21	43.232
Hydrogen Content, wt. %	C-M-40	11.66	C-M-23	C-M-38	13.34	C-M-21	14.04
Carbon Content, wt. %	C-M-45	85.53	C-M-49	C-M-44	86.21	C-M-40	87.69
Cetane No.	C-M-40	36.8	C-M-48	C-M-17	30.9	C-M-21	64.4
Cetane Index	C-M-27	37.5	C-M-47	C-M-19	51.5	C-M-21	62.2
Diesel Index	C-M-89	34.3	C-M-17	C-M-49	55.1	C-M-21	74.7
Aniline Point, °C	C-M-89	47.25	C-M-47	C-M-48	68.60	C-M-21	86.80
Aromatics, wt. %	C-M-12	27.5	C-M-88	C-M-18	38.8	C-M-27	51.8
Polars, wt. %	C-M-33	0.2	(11 fuels)	——	0.4	C-M-40	10.8
Saturates, wt. %	C-M-40	35.1	C-M-18	C-M-87	60.8	C-M-12	72.2
Asphaltenes, wt. %	(32 fuels)	<0.1	(32 fuels)	——	<0.1	C-M-40	2.3
Ash, wt. %	(20 fuels)	<0.0001	(20 fuels)	——	<0.0001	C-M-27	0.0080
Aluminum, ppm wt.	C-M-21, 44,47	<0.01	(6 fuels)	——	0.02	C-M-27,40	0.28
Calcium, ppm wt.	C-M-20	<0.01	C-M-24	C-M-18	0.09	C-M-27	2.13
Copper, ppm wt.	C-M-19, 26,88	<0.01	C-M-14	C-M-47	0.03	C-M-89	0.42
Iron, ppm wt.	C-M-42,26	0.01	C-M-36	C-M-17	0.19	C-M-27	2.49
Lead, ppm wt.	(7 fuels)	0.01	(6 fuels)	——	0.05	C-M-47	0.94
Nickel, ppm wt.	(9 fuels)	<0.01	C-M-33	C-M-11	<0.02	C-M-40	7.60
Silicon, ppm wt.	C-M-18, 38,39	<0.01	C-M-27	C-M-13	0.10	C-M-47	1.16
Potassium, ppm wt.	(14 fuels)	<0.01	(5 fuels)	——	0.01	C-M-33	0.33
Sodium, ppm wt.	C-M-44	0.03	(3 fuels)	——	0.09	C-M-40	1.78
Vanadium, ppm wt.	C-M-19,24	<0.01	C-M-38	C-M-20	0.03	C-M-27,40	6.3

Table 5. Analytical data for Heavy Marine Gas Oils (HMGO, 6 samples)

Fuel Property	Low		Median			High	
	ID	Value	ID	ID2	Value	ID	Value
Distillation, D 86/1160							
Initial Boiling Point, °C	C-H-87	174.0	C-H-21	C-H-43	211.0	C-H-36	276.0
50% Point, °C	C-H-87	276.0	C-H-23	C-H-30	309.3	C-H-43	448.0
90% Point, °C	C-H-87	337.5	C-H-21	C-H-30	372.0	C-H-43	598.0
End Point, °C	C-H-23	365.0	C-H-21	------	387.0	C-H-36	398.5
Distillation, D 2887							
Initial Boiling Point, °C	C-H-87	115.5	C-H-21	------	128.0	C-H-36	194.0
50% Point, °C	C-H-87	270.5	C-H-23	------	318.5	C-H-36	377.5
90% Point, °C	C-H-87	357.0	C-H-21	------	388.5	C-H-36	435.5
End Point, °C	C-H-87	425.0	C-H-30	------	473.0	C-H-36	506.0
Gravity, °API	C-H-43	20.6	C-H-21	C-H-30	32.7	C-H-87	38.3
Viscosity @ 40° C, mm²/sec	C-H-87	2.555	C-H-23	C-H-30	4.761	C-H-43	90.35
Viscosity @ 100° C, mm²/sec	C-H-87	1.092	C-H-23	C-H-30	1.640	C-H-43	8.871
Flash Point, °C	C-H-87	61.5	C-H-21	C-H-23	91.5	C-H-43	150
Cloud Point, °C	C-H-87	-7	C-H-23	C-H-30	2.5	C-H-36	12
Pour Point, °C	C-H-87	-21	C-H-30	C-H-36	3	C-H-43	18
Color	C-H-87	0.5	C-H-36	C-H-23	6.5	C-H-43	D8.0
Surface Tension, dynes/cm	C-H-87	26.0	C-H-21	C-H-30	28.35	C-H-43	30.0
Interfacial Tension, dynes/cm	C-H-36	9.5	C-H-23	C-H-30	17.25	C-H-87	23.0
Water & Sediment, vol. %	C-H-87	<0.005	C-H-23	------	0.010	C-H-21	0.025
Particulates, mg/L *	C-H-87	0.14	C-H-87	C-H-30	1.18	C-H-30	2.22
Sulfur, wt. %	C-H-43	0.18	C-H-21	C-H-87	0.575	C-H-36	1.49
Acid No., mg KOH/g	C-H-21	0.06	(3 fuels)	------	0.08	C-H-36	1.40
Carbon Residue, on 10% bottoms, wt. %	C-H-87	0.09	C-H-36	------	0.28	C-H-21	0.35
Accelerated Stability, mg/100 mL	C-H-87	0.06	C-H-23	------	0.26	C-H-21	1.01
FSII, wt. %	C-H-21,36	0.048	C-H-23,30	------	0.053	C-H-87	0.069
Heat of Combustion, MJ/kg	C-H-43	41.796	C-H-21	C-H-23	42.477	C-H-87	42.758
Hydrogen Content, wt. %	C-H-43	12.17	C-H-21	C-H-30	13.00	C-H-87	13.66
Carbon Content, wt. %	C-H-36	85.60	C-H-30	C-H-23	86.28	C-H-43	86.58
Cetane No.	C-H-36	43.1	C-H-30	------	49.6	C-H-23	55.6
Cetane Index	C-H-43	26.4	C-H-21	C-H-30	49.3	C-H-87	54.7
Diesel Index	C-H-36	41.7	C-H-30	------	56.6	C-H-87	60.1
Aniline Point, °C	C-H-21	67.80	C-H-36	------	72.40	C-H-23	76.60
Aromatics, wt. %	C-H-23	31.6	C-H-30	C-H-87	38.2	C-H-21	48.2
Polars, wt. %	C-H-23,87	0.4	C-H-21	C-H-30	1.1	C-H-43	12.9
Saturates, wt. %	C-H-21	51.0	C-H-36	C-H-87	56.9	C-H-23	68.0
Ash, wt. %	C-H-36,87	<0.0001	C-H-23	C-H-30	0.0006	C-H-43	0.0129
Aluminum, ppm wt.	C-H-30,36	<0.01	C-H-30	C-H-23	0.02	C-H-43	0.87
Calcium, ppm wt.	C-H-23	<0.04	C-H-30	C-H-87	0.31	C-H-43	3.22
Copper, ppm wt.	C-H-87	<0.01	C-H-36	C-H-23	0.01	C-H-43	0.18
Iron, ppm wt.	C-H-87	<0.04	C-H-36	C-H-21	0.46	C-H-43	6.25
Lead, ppm wt.	C-H-87	<0.01	C-H-36	C-H-30	0.04	C-H-43	0.35
Nickel, ppm wt.	C-H-87	<0.01	C-H-36	C-H-23	0.04	C-H-43	1.93
Silicon, ppm wt.	C-H-23, 30,36	<0.04	C-H-23	C-H-21	0.05	C-H-43	3.41
Potassium, ppm wt.	C-H-24, 30,36,87	<0.01	C-H-36	C-H-23	0.01	C-H-43	0.72
Sodium, ppm wt.	C-H-30, 36,87	<0.04	C-H-30	C-H-23	0.05	C-H-43	36.87
Vanadium, ppm wt.	C-H-87	<0.03	C-H-36	C-H-21	0.10	C-H-43	6.59

* Only two fuels could be filtered, others plugged the filter.

Table 6. Analytical data for Marine Diesel Fuels (MDF, 10 samples)

Fuel Property	Low		Median			High	
	ID	Value	ID	ID2	Value	ID	Value
Distillation, D 86/1160							
Initial Boiling Point, °C	C-D-34	171.0	C-D-12	C-D-36	206.3	C-D-30	239.5
50% Point, °C	C-D-33	278.5	C-D-15	C-D-30	318.8	C-D-34	466.0
90% Point, °C	C-D-33	331.0	C-D-30	------	388.5	C-D-24	395.5
End Point, °C	C-D-33	356.5	C-D-30	C-D-42	394.3	C-D-34	540.5
Distillation, D 2887							
Initial Boiling Point, °C	C-D-42	117.0	C-D-12	C-D-15	149.5	C-D-24	173.0
50% Point, °C	C-D-33	281.0	C-D-15	C-D-30	330.3	C-D-34	446.0
90% Point, °C	C-D-33	355.5	C-D-15	------	410.5	C-D-26	465.5
End Point, °C	C-D-12	407.0	C-D-24	C-D-30	536.5	C-D-26	553.5
Gravity, °API	C-D-34	16.5	C-D-12	C-D-24	31.5	C-D-33	36.9
Viscosity @ 40° C, mm²/sec	C-D-33	2.874	C-D-15	C-D-24	6.639	C-D-34	151.3
Viscosity @ 100° C, mm²/sec	C-D-33	1.170	C-D-24	C-D-30	2.225	C-D-34	12.01
Flash Point, °C	C-D-33	71.5	C-D-26	C-D-36	89.5	C-D-24	103.5
Pour Point, °C	C-D-33	-21	C-D-26	C-D-15	8	C-D-26	21
Demulsification @ 25° C, min.	C-D-33	1	C-D-36	------	12	C-D-26	100
Color	C-D-33	L0.5	C-D-26	C-D-24	L5.0D	C-D-23, 30,34,42	D8.0D
Surface Tension, dynes/cm	C-D-33	25.8	C-D-26	C-D-15	28.7	C-D-34	30.1
Interfacial Tension, dynes/cm	C-D-24	6.5	C-D-23	------	12.0	C-D-33	21.0
Water & Sediment, vol. %	C-D-12, 26,33	<0.005	C-D-24	------	0.025	C-D-42	0.560
Particulates, mg/L	C-D-12	1.22	C-D-12	C-D-26	5.61	C-D-26	10.00
Sulfur, wt. %	C-D-33	0.22	C-D-23	C-D-36	1.18	C-D-26	2.25
Acid No., mg KOH/g	C-D-12	0.02	C-D-24	C-D-42	0.09	C-D-36	1.19
Carbon Residue,							
on 10% bottoms, wt. %	C-D-33	0.10	C-D-24	------	1.84	C-D-23	12.84
Accelerated Stability, mg/100 mL	C-D-12	0.17	C-D-36	C-D-24	0.65	C-D-23	8.03
FSII, wt. %	C-D-12	0.044	C-D-24	------	0.051	C-D-23	0.102
Heat of Combustion, MJ/kg	C-D-34	40.844	C-D-36	C-D-24	42.315	C-D-33	42.774
Hydrogen Content, wt. %	C-D-34	11.14	C-D-36	C-D-24	12.85	C-D-15	13.46
Carbon Content, wt. %	C-D-30	85.26	C-D-36	C-D-34	85.84	C-D-12	87.72
Cetane No.	C-D-30	42.0	C-D-23	------	50.1	C-D-24	59.7
Cetane Index	C-D-34	17.8	C-D-36	C-D-42	47.6	C-D-33	52.8
Diesel Index	C-D-26	38.3	C-D-42	C-D-24	54.8	C-D-33	57.0
Aniline Point, °C	C-D-12	58.20	C-D-36	C-D-23	71.13	C-D-24	78.55
Aromatics, wt. %	C-D-15	29.7	C-D-23	C-D-30	42.9	C-D-12	50.2
Polars, wt. %	C-D-33	0.1	C-D-24	C-D-30	3.0	C-D-34	9.0
Saturates, wt. %	C-D-34	35.2	C-D-30	C-D-23	52.85	C-D-15	68.6
Asphaltenes, wt. %	(5 fuels)	<0.1	C-D-36	C-D-24	0.1	C-D-34	10.0
Ash, wt. %	C-D-24, 26,36	<0.0001	C-D-12	C-D-15	0.0011	C-D-34	0.0358
Aluminum, ppm wt.	C-D-23, 24,26	<0.02	C-D-12	C-D-15	0.02	C-D-34	25.0
Calcium, ppm wt.	C-D-15, 26,42	<0.06	C-D-12	C-D-24	0.20	C-D-34	4.82
Copper, ppm wt.	(5 fuels)	0.01	C-D-26	C-D-15	0.02	C-D-34	0.08
Iron, ppm wt.	C-D-26	<0.01	C-D-42	C-D-23	0.29	C-D-34	14.0
Lead, ppm wt.	C-D-15	<0.01	C-D-26	C-D-36	0.03	C-D-34	0.20
Nickel, ppm wt.	C-D-12, 33,36	<0.02	C-D-15	C-D-24	0.12	C-D-34	19.2
Silicon, ppm wt.	C-D-36	0.04	C-D-24	C-D-15	0.09	C-D-34	58.0
Potassium, ppm wt.	C-D-15, 26,33,36	<0.01	C-D-36	C-D-42	0.01	C-D-34	0.70
Sodium, ppm wt.	C-D-33,36	<0.04	C-D-15	C-D-23	0.14	C-D-34	22.6
Vanadium, ppm wt.	C-D-12,26	<0.03	C-D-36	C-D-24	0.29	C-D-34	43.4

Only six samples of commercial HMGOs were characterized in this study; this is not a statistically strong data set, but the analytical data in Table 5 do provide information about commercially available marine fuels of this type. Fuel C-H-43 from Peru was the most difficult HMGO fuel to analyze. Distillation was performed under vacuum, but cracking still occurred with about 11.5 vol % of the sample remaining in the distillation pot. This sample had a low API gravity and heat of combustion, with high viscosity, polars, and metals contents. Probably the better fuel in this group based on these data is C-H-87 from Korea. It has higher API gravity, heat of combustion, and cetane index, with lower cloud, pour, viscosity, carbon residue, instability, polars, and metals.

Ten samples of commercial MDFs as listed in Table 6 were characterized. These fuels by definition can contain a higher percentage of residual fuel stocks and, therefore, are typically heavier, dirtier fuels. Fuel C-D-34 from Thailand was the most difficult of this type to analyze. It cracked during vacuum distillation at 516°C with 34.5 vol % of the charge remaining in the still pot. Because of the nature of this sample, troubles were also encountered with several other test procedures: cloud point, demulsification, water and sediment, particulates, acid number, accelerated stability, FSII, cetane number, and aniline point. Fuel C-D-34 is probably the lowest quality MDF fuel, and C-D-33 from Sweden is probably the highest quality.

QUALITY CONTROL

Quality control procedures followed by NIPER for the commercial marine fuel and F-76 fuel surveys included but were not limited to the following. Careful adherence to these established procedures helped ensure that generated data were of known quality and integrity to meet project objectives.

1. Immediately upon sample arrival at NIPER, containers were examined for damage, and the sample was assigned a unique laboratory number (Navy numbers were also used) which was used to trace sample status throughout the testing procedures. The sample number was placed on the container and in the laboratory logbook along with any other pertinent information.
2. All samples awaiting testing were stored in a temperature controlled area at 40 degrees Fahrenheit.
3. Samples were permitted to warm to room temperature and shaken with an electric-powered can shaker before the container was opened for removal of aliquots for analysis, or for shipping to other laboratories.
4. All aliquots removed from the original container were also labeled with the same sample number as the original container, except blind samples which were given another unique number by the laboratory supervisor. Information regarding the blind sample numbers and the corresponding original sample numbers was kept confidential in a separate logbook.
5. Approximately 10 percent of the submitted samples were analyzed as NIPER blind and/or duplicate samples.
6. Test methods were those mutually agreed upon by DTRC and NIPER. Appropriate ASTM Standards or Federal Test Methods were followed as much as possible. Standards, performance control samples, spiked samples, and reagent blanks were included in appropriate analytical sequences.
7. All raw analytical data were entered in lab books along with any documentation of instrument performance checks, calibrations, or abnormalities. Analysts performing the test initialed and dated the test results in lab books. Lab books were monitored and witnessed by the laboratory supervisor on a periodic basis.

8. All standards employed for calibration purposes consisted of known high purity reference material. Whenever possible, standards were selected that were traceable to NBS standards.
9. The grade or purity of solvents, reagents, and gases required varied for different analytical procedures; however, those used met or exceeded the quality specified in the procedures.
10. Analytical results for standards and samples run in duplicate were compared to the repeatability statements in applicable standard procedures, and to known values in the case of standards or spiked samples to ensure valid data were being generated.
11. All typed data were checked against original data before transmitting to DTRC.

The data in Table 7 show a comparison of blind sample analytical results with those of the fuels from which the blinds were taken. The method repeatability values in Table 7 are optimum values as established by ASTM, except "repeatability values" listed for ASTM Method D 3605 (modified) were established at NIPER.

While there were several test result differences that exceeded the stated repeatability limits, very few were as excessively different as particulates for C-M-24/P-W-1 or silicon for C-M-43/P-W-8. Again, consideration must be given to the character of the fuels under test, which in most cases are non-typical for the standard test methods specified in military specifications for F-76 fuels and used in this study.

Table 7. Comparison of blind sample analytical results with those of the fuels from which the blinds were taken

Property	Method reference	Method repeatability	C-M-24	Blind P-W-1	N-F-78	Blind P-W-3	C-M-12	Blind P-W-4	N-F-54	Blind P-W-5	C-M-38	Blind P-W-6	N-F-80	Blind P-W-7	C-M-43	Blind P-W-8
Distillation, IBP °C	D 86	3.5	186.5	188.5	202.0	199.0	208.0	204.0	189.5	191.5	185.5	184.5	182.5	192.0	165.5	169.5
50%		2.2	288.5	289.0	283.5	284.0	280.5	280.0	279.5	279.0	275.5	275.5	272.5	270.5	306.5	307.0
90%		3.2	340.0	340.5	330.5	331.0	317.0	316.0	334.0	330.0	336.0	7.0	336.5	336.0	355.5	354.5
EP		3.5	365.5	365.5	356.5	357.5	340.5	339.5	362.0	361.0	366.5	.5	368.5	368.0	378.5	380.0
Specific gravity	D 1298	0.0006	0.8489	0.8489	0.8474	0.8473	0.8383	0.8382	0.8474	0.8472	0.8431	0.8431	0.8400	0.8405	0.8634	0.8635
Viscosity, 40°C, mm^2/sec	D 445	0.35% of mean	3.321	3.318	3.325	3.304	3.119	3.109	3.122	3.105	2.876	2.864	2.859	2.856	4.324	4.316
Flash point, °C	D 93	2	76.5	76.5	77.5	78.0	80.5	80.5	73.5	73.5	69.5	69.5	69.5	69.0	61.5	62.5
Cloud point, °C	D 2500	2	-2	-2	-6	-6	-3	-4	-6	-6	-4	-4	-2	-2	-6	-7
Pour point, °C	D 97	3	-7	-7	-9	-9	-6	-6	-12	-12	-24	-21	-12	-12	-9	-12
Demulsification, 25°C, min	D 1401	±1.5	3.0	3.0	2	1	2	2	2	2	4	2	1	2	3	1
Surface tension, dynes/cm	D 1331	---	27.8	26.7	30.0	29.7	25.7	26.2	30.2	29.0	28.2	27.4	28.0	28.0	27.0	27.5
Interfacial tension, dynes/cm	D 1331	---	10.5	14.5	15.0	18.0	23.0	19.5	13.0	13.0	19.5	19.0	17.5	19.5	21.5	18.0
Water and sediment, vol %	D 2709	---	<0.005	<0.005	0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Particulates, mg/l	D 2276	0.5	0.65	1.22	0.69	1.95	2.19	3.09	1.17	1.45	2.89	3.66	2.65	2.42	1.55	1.68
Asphaltenes, wt %	D 2007	<0.1	<0.1	<0.1	---	---	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sulfur, wt %	D 4294	0.04	0.91	0.91	0.51	0.51	0.36	0.36	0.60	0.63	0.28	0.28	0.49	0.49	0.38	0.38
Acid number, mg KOH/g	D 664	6% of mean	0.04	0.02	0.05	0.04	0.07	0.08	0.07	0.06	0.04	0.04	0.06	0.07	0.08	0.09
Corrosion at 100°C	D 130	---	1B	1B	1A	1B	1A	1B	1A	1A	1A	1A	1A	1A	1B	1B
Carbon residue, 10%, wt %	D 524	0.03	0.14	0.17	0.12	0.11	0.08	0.10	0.11	0.13	0.13	0.11	0.14	0.15	0.12	0.10
Accelerated stability, mg/100 ML	D 2274	0.3	0.46	0.20	0.97	0.79	0.19	0.16	1.84	1.70	0.39	0.30	0.54	0.53	0.57	0.87
Net heat of comb, MJ/kg	D 2382	0.07	42,528	42,544	42,674	42,674	42,754	42,760	42,662	42,658	42,734	42,728	42,718	42,716	42,590	42,590
Hydrogen, wt %	PE 240	±0.11% abs	12.98	12.96	13.36	13.49	13.54	13.51	13.22	13.18	13.34	13.54	13.46	13.48	13.24	13.22
Carbon, wt %	PE 240	±0.18% abs	86.06	85.95	86.08	85.83	86.49	86.38	86.25	86.22	86.08	86.54	86.10	86.00	86.26	86.58
Cetane number	D 613	0.7	51.8	49.6	48.6	48.2	58.3	51.6	49.5	49.6	49.3	51.7	50.6	51.2	49.8	48.5
Aniline point, °C	D 611	0.3	66.45	66.40	69.25	69.30	72.40	72.40	67.70	68.10	66.40	66.50	67.70	67.75	69.75	69.35
Ash, wt %	D 482	0.003	<0.0001	<0.0001	<0.0001	<0.0001	0.0009	0.0011	0.0002	<0.0001	<0.0001	0.0005	0.0018	<0.0001	<0.0001	<0.0001
Saturates, wt %	D 2007	0.8	54.2	48.2	---	---	72.2	72.3	59.8	65.6	60.1	60.7	64.1	64.9	65.8	65.0
Polars, wt %	D 2007	0.9	0.2	0.2	---	---	0.3	0.2	0.5	0.4	0.2	0.3	0.5	0.6	0.6	0.7
Aromatics, wt %	D 2007	1.5	45.6	51.6	---	---	27.5	27.6	39.7	34.1	39.7	39.0	35.5	34.5	33.6	34.3
Aluminum, ppm wt	D 3605(m)*	±0.005	0.04	0.04	<0.03	<0.03	0.02	0.03	0.04	<0.02	<0.02	<0.02	0.07	0.02	0.03	<0.02
Calcium, ppm wt	"	±0.01	0.08	0.08	0.06	0.12	0.32	0.25	0.21	0.27	0.11	0.06	0.10	<0.06	<0.06	<0.06
Copper, ppm wt	"	±0.005	0.01	0.01	0.14	0.13	0.04	0.02	0.15	0.11	0.04	0.03	0.04	0.04	0.06	0.06
Iron, ppm wt	"	±0.01	0.30	<0.05	0.05	0.06	0.72	1.34	0.09	<0.04	0.15	0.18	<0.04	<0.04	0.06	0.10
Lead, ppm wt	"	±0.01	0.01	0.02	0.03	0.03	0.05	0.03	0.03	0.02	0.13	0.12	0.04	0.04	0.63	0.84
Nickel, ppm wt	"	±0.005	0.01	0.01	<0.02	<0.02	0.01	<0.02	0.01	0.04	0.01	0.01	<0.01	<0.01	0.07	<0.01
Silicon, ppm wt	"	±0.01	<0.10	<0.10	<0.04	<0.04	<0.06	<0.06	<0.04	<0.01	<0.01	0.01	0.12	0.05	0.78	1.20
Potassium, ppm wt	"	±0.05	0.05	0.03	0.09	<0.01	0.03	0.03	<0.01	<0.01	0.02	0.01	0.02	<0.01	0.02	<0.01
Sodium, ppm wt	"	±0.05	0.13	0.20	0.21	0.21	<0.04	<0.04	0.14	0.12	0.12	0.09	0.09	0.09	<0.04	0.06
Vanadium, ppm wt	"	±0.01	<0.01	0.19	<0.04	<0.04	<0.05	<0.05	<0.03	<0.03	0.03	0.04	<0.03	<0.03	<0.03	<0.03

* Modified method.

Examination of the data in Table 7 gives an indication of the test methods that most likely need some modification for optimized testing of marine fuels: particulates, cetane number, hydrocarbon types, metals contents, and others as discussed elsewhere in this report. Examination also indicates a high level of integrity for the data generated in this project, and that the data will be useful in the evaluation of properties of the world's marine fuel supply.

SUMMARY AND RECOMMENDATIONS

Data generated in this survey may be compared by fuel type to those of an earlier survey conducted by DTRC (Burnett et al.[10]) to evaluate the world's fuel supply that meets or nearly meets F-76 fuel specifications. Portions of the data generated in this and the earlier survey were presented at meetings of the Society of Automotive Engineers (Shaver et al.[11] and Modetz et al.[12]). One of the main conclusions of these studies is the fact that there is a vast supply of marine fuel that could be used by the U.S. Navy fleet, in the event of an emergency, without adverse effects on engine operation.

ABSTECH was not able to obtain samples in some planned locations because of various restrictions beyond their control. To help complete the worldwide marine fuels data base, further attempts should be made in future surveys to secure samples and to survey the fuel depots in the currently inaccessible areas.

As expected, the heavy fuels, HMGO, and MDF fuels, were the most difficult to analyze with desired precision, and F-76 fuels were the least difficult. Some of the test methods could be further refined to analyze these type fuels, and it is recommended that this work be done prior to, or concurrently with, any subsequent survey. Fuels C-H-21 from Indonesia and C-D-34 from Thailand gave the most trouble

with the testing procedures. Fuel C-H-21 had sand and water present that caused trouble with several tests, and C-D-34 contained an excessive amount of residual material which also caused testing problems.

Prior to conducting a future program of this nature, analytical methods need to be reevaluated and consideration given to better use of improved test methods. Standards development organizations such as ASTM are constantly developing new methods and revising existing methods. The scope of these methods needs to be studied for applicability to fuels to be tested. An example of the prescribed test method being inappropriate for marine fuels is ASTM D 2276 for particulates. In many cases, additional developmental research needs to be done to optimize procedures. NIPER did some developmental work for this project, but much more needs to be done.

Some military specifications for fuels list obsolete or, at best, poor test methods. These need to be kept more current to take better advantage of continual new developments in the field of analytical chemistry. A good example of this is the Ramsbottom test for carbon residue (ASTM D 524). A micro-carbon residue apparatus (ASTM D 4530) is available that is easier to use and provides more precise carbon residue values, especially for heavy or residual type fuels. Other examples are ASTM D 1298 for gravity and ASTM D 974 for acid number, as compared to the better methods D 4052 and D 664, respectively, for these tests.

APPENDIX

SURVEY FUEL ANALYSTS' INITIALS AND CORRESPONDING NAMES

The following personnel performed the various analyses of fuels in this survey. Their initials were reported on final analysis forms for individual tests of each sample.

Initial	Name	Initial	Name
KB	Kathleen Bertus	PP	Phillips 66 R&D
SB	Sushma Bhan	JR	Jim Reynolds
RB	Rebecca Bryant	LR	Lori Roark
LC	Laura Carter	JS	Johanna Shay
LAC	Lori A. Cullins	NS	Norris Smith
BD	Brad Diehl	BS	Bill Steele
JD	Jonell Douglas	AS	Anita Stepp
SHG/SG	Suzie H. Gassett	KS	Kathy Stirling
JG	JoAnn Gillispie	MT	Mei Tang
JWG	John W. Goetzinger	RLT	Roy Tate
JG	Judy Green (metals)	JT	Jane Thomson
MH	Mike Hefner	MW	Mary White
ML	Mary Lowe	PDW	Paul Wolfe

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